Columbia University in the City of New York
Lamont Geological Observatory
Palisades, New York

Six-month Status Report: September, 1964 - February, 1965

Grant NsG 232-62

Research on Quantities and Concentrations of Extraterrestrial Matter through Samplings of Ocean Bottoms.

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I. Work Accomplished

During the period September, 1964 - February, 1965 project research was carried out in the categories of optical and electron microscope studies of polished sections of natural spherules, magnetic separations on ocean-bottom trawling samples, nondestructive radioactivation analysis of spherules, and model studies on underwater cratering. The last category is a new one, and shows promise of very interesting results. These activities are discussed in more detail below and in the following pages.

A. Magnetic and non-magnetic separations on flow-in samples.

This remains a part of the research program but little was done on it during the period of this report.

B. Polished-section examinations.

Figs. 1 & 2 show the polished and etched section of a magnetic spherule 250 microns in diameter. Three phases are visible in Fig. 2; these are matrix material of unknown composition, subparallel inclusions, probably of iron oxide, and bright metallic spots usually located at an interface between the two main phases. Note the radial arrangement of iron oxide inclusions reminiscent of structures found in siliceous chondrules. The presence of unoxidized metal tends to cast doubt on a terrestrial volcanic origin for this spherule of natural origin.

A number of electron photomicrographs have been made at different magnifications of the etched surface of this spherule.

Apparent relief in these photos is inverted from the true relief of the etched surface. Thus, the bright oxide network seen in Figs. 1 & 2 appears to have been selectively etched away, leaving the matrix material relatively more prominent. Actually, however, the oxide network was etched less than the matrix. Initial etching removed the metallic inclusions completely, and their former sites are not visible in any of the peels.

As seen in Fig. 3, the grain size in the matrix material is not discernible even at a magnification of 4000x, although there is an indication of large grains imbedded in finer-grained matrix material. This could be due to etching effects, a bimodal distribution of grain sizes in the same phase, or the presence of two different crystalline phases in the matrix. A lighter etching treatment, shown in Fig. 4, produced a distinct bimodal effect in the matrix material, with many of the lumpy aggregates giving an appearance of crystal faces.

Deeper etching and higher magnifications will be necessary to study the matrix material more closely.

In view of our finding that Fe is the only major rock-forming cation in most natural spherules we have examined, the presence of three or four phases of different composition in one such spherule is hard to explain. Of course iron can exist as metallic iron and also in the oxide forms of wustite ($Fe_{1-x}O_1$), magnetite [$(FeO)_x(Fe_2O_3)_{1-x}$], and hematite (Fe_2O_3), but these three or four phases would not be expected in equilibrium. If terrestrial weathering were important, however, equilibrium conditions would no longer prevail, and the additional hydrated forms goethite [FeO(OH)] and limonite (variable composition) might be expected.

C. Trawling collections.

The rare-gas analyses on magnetic fractions of our trawl collections formerly being carried out by Merrihue and by Merrihue and Tilles have been suspended temporarily due to Merrihue's death. They will be continued and expanded by Tilles, however, and our magnetic separations on red clay samples are continuing for that purpose. Unofficial results from another laboratory suggest the finding of a non-rare-gas cosmogenic isotope in red clay material supplied by us, and if this preliminary finding is confirmed it will further strengthen the suspicion that some one or more components of oceanic red clays other than microscopic spherules are also of extraterrestrial origin.

D. Radioactivation analysis.

A series of runs was made on a black, very shiny, nonmagnetic spherule 180u in diameter. This spherule (from Lamont core A 167-1, 37°39'N; 72°57.5'W) came from 225 km SE of Cape May. Previous irradiations had produced negligible activity in this spherule, and it is assumed to be hollow. The current series of irradiations was of five-and ten-minute duration, and some activity was induced by these. Early runs showed the presence of Mn^{56} and Na^{24}, but best results were obtained after a ten-minute irradiation (Run NS 1-5), where, using a new-design fast-opening rabbit we were able to begin counting 4 min. 49 sec. after the end of irradiation. One-minute counts were made to study short half-life nuclides such as Al^{28} (2.4m) and Mg^{27} (10.2m). The ten-minute irradiation time, roughly four half-lives of Al^{28}, was long enough to insure virtual equilibrium between production and decay of Al^{28}, while keeping the longer half-lived nuclides below their equilibrium values. The resulting spectra contained peaks for Mn^{56} and Na^{24}, but the first few also suggested an Al^{28} peak. In order to improve the statistics, a plot of total count vs time was made and showed early decay with a half-life around 2.8 minutes, strongly suggesting the presence of Al and/or Si in the spherule. Subsequent decay of the total spectrum proceeded with a half-life of approximately 20 min., suggesting the possibility of Mg^{27} being among the irradiation products. Thus this spherule appears to have at least minor quantities of the normal rock-forming cations. Its highly reflecting surface and lack of magnetism also suggest a natural glass. The spherule is interesting because it is quite different from the one other natural glassy specimen we have found in ocean sediments. Analysis of the spectra is continuing.

E. Model studies on underwater cratering.

There are thirteen well-authenticated sites in the world where falling meteoritic masses have been large enough or energetic enough to cause craters in the earth. All these known craters are of Recent or Pleistocene Age. Many other older sites whose morphology is craterlike are of suspected impact origin, and most of these are many kilometers in diameter. We suggest that a meteorite large enough to cause cratering on land should leave some trace on the ocean floor if it falls into the sea. Two mechanisms are possible: actual cratering of the ocean floor if the meteorite is large enough, or production of some non-craterlike circular feature due to shock-wave effects if the crater itself does not reach the ocean floor.

A model study of underwater cratering was projected in the previous six-month report, and preliminary results on this are now available. A rather crude experimental setup sufficed for the initial work; this is shown in Fig. 5. The impact environment consisted of a small body of water overlying mud. The impact of a crater-forming meteorite was simulated by the explosion of a one-foot length of Primacord PETN 400 detonating fuse, seen hanging below the tripod in Fig. 5. This fuse is initially detonated with a blasting cap. Once started, the detonation travels along the length of the fuse at 5-6 Km/sec, causing a shock front propagating downward. This simulates the shock effects produced along the path of a meteorite falling through the atmosphere. If the bottom end of the Primacord length extends below the water or mud surface the detonation of this end part simulates the crater-forming impact, along with its associated shock wave.

Results of the three cases studied are shown in Figs. 6,7 & 8, and dimensions of the craterlike features produced are listed in Table 1. In Case 1 (Fig.6) the primacord was suspended vertically with its bottom end in the air about 3/4" above the water surface. Depth of the water was about 3/4". This arrangement simulates an air blast of the Podkammenaya-Tunguska type, which occurred in Russia in 1908, in which presumably only shock effects were significant. Note that a small depression was produced in the mud by the shock wave. In Case 2 (Fig. 7) the primacord was suspended vertically with its bottom end 1/4" below the water surface to simulate a craterforming meteorite hitting water. Depth of the water was 7/8". The crater produced was much larger, presumably due to the tamping effect of the overlying water and the addition to the shock-wave of the crater-forming effect of the explosion. The crater is square-shaped, due possibly to edge effects from the dirt walls. It was surprising that no pronounced rims were produced; judging by material deposited on surrounding foliage, most ejecta shot up at a high angle in a jet or cone of water and mud. In Case 3 (Fig. 8) the primacord was suspended vertically over a mud surface with the end extending 1" into the mud. There was no overlying water. This situation was thought to be closer to a crater-forming meteorite striking a land surface. The crater produced was appreciably smaller and shallower than the underwater explosion and definite rims of ejected material were present. Relative depths of the three craters may not be particularly significant in this series of experiments because we had poor control over depth of the

Table 1. Parameters and Results of Model Cratering Experiments

	Angle of incidence of shock wave	Medium in which blast occurred	Depth of blast below surface of medium	Depth of water	Diam. of crater	Depth of crater	Diam.: Depth
Case 1	vertical	air	--	3/4"	6 1/4" x 7 1/4"	1/2"	13.5
Case 2	vertical	water	1/4"	7/8"	16"x17"	2 1/2"	6.6
Case 3	vertical	mud	1"	0	12 1/2" x 14 1/2"	2 1/4"	6.0

underlying mud, and bottom effects may have been appreciable. We feel, however, that the results obtained to date justify a more elaborate series of experiments. The one tentative conclusion reache so far is that shock effects alone produce a larger diameter/depth feature in water than explosion cratering.

II. Projected Work

A. Magnetic and non-magnetic separations on flow-in samples.

Magnetic separation work will be continued in connection with our continuing effort to supply samples to laboratories requiring them in their search for cosmogenic nuclides. Magnetic separations for spherules from our own collections will be carried out concurrently, and microscopic search of the nonmagnetic fractions of red clay cores will be continued.

B. Polished-section examinations.

The question of the possible existence of two phases, or a bimodal distribution of grain sizes, in the matrix material of the natural spherule examined is an interesting one. While the reflecting oxide network looks like a quench phenomenon, the equidimensional crystals found in the matrix material look less like quench interfaces between the reflecting oxide network and the groundmass material suggest that terrestrial oxidation has not been important, and the observed phases are part of the preterrestrial fabric of the spherule.

Peel studies are capable of greater refinement and greater enlargement. This will be done, and more natural spherules will be examined by means of optical photomicrography coupled with electron photomicrography.

C. Trawling collections.

Trawling collections are being made continually by the VEMA and CONRAD, and examination of them for extraterrestrial material will continue. A series of trawl runs with a five-foot Blake trawl was scheduled south of Australia in the hope of dredging up australites. The arrival of these sediment collections is presently awaited.

D. Nondestructive radioactivation analysis.

A proposal has been submitted to NASA for examination of samples of lunar dust and lunar rock fragments, to be carried out largely under the present grant. An important part of this new work would involve nondestructive radioactivation analysis of the samples. It is expected that these samples will contain more of the major rock-forming cations than have the magnetic spherules analyzed to date, and that the techniques for rapid analysis of these components evolved under the present grant will prove very useful in this endeavor. Two approaches to the analytical problem are being considered, as follows:

1. Elemental analysis. Standard spectra would be obtained for up to ten elements expected to be in the samples. A computer program would be set up to carry out least

squares solutions for these spectra in spectra of samples of unknown composition.

2. Spectrum analogy. Standard spectra would be obtained for as many rock types as possible. The spectrum of an unknown rock could then be compared to these and its compositional type determined by analogy with the spectra of known rock types.

A decision between these two methods has not yet been made, and elements of both may be adopted. A start will be made on obtaining the basic data necessary to both.

E. Model studies on underwater cratering.

This work will continue by examining the effects produced by variations in the depth of water and angle of infall. Eventually a more controllable impact environment will be sought, either by construction of better facilities or by seeking the loan of existing facilities at another site.

III. Acknowledgment

The opportunity to carry out the work described in this report, made possible by NASA Grant 232-62, is gratefully acknowledged.

Respectfully submitted,

William A. Cassidy
(Research Scientist)

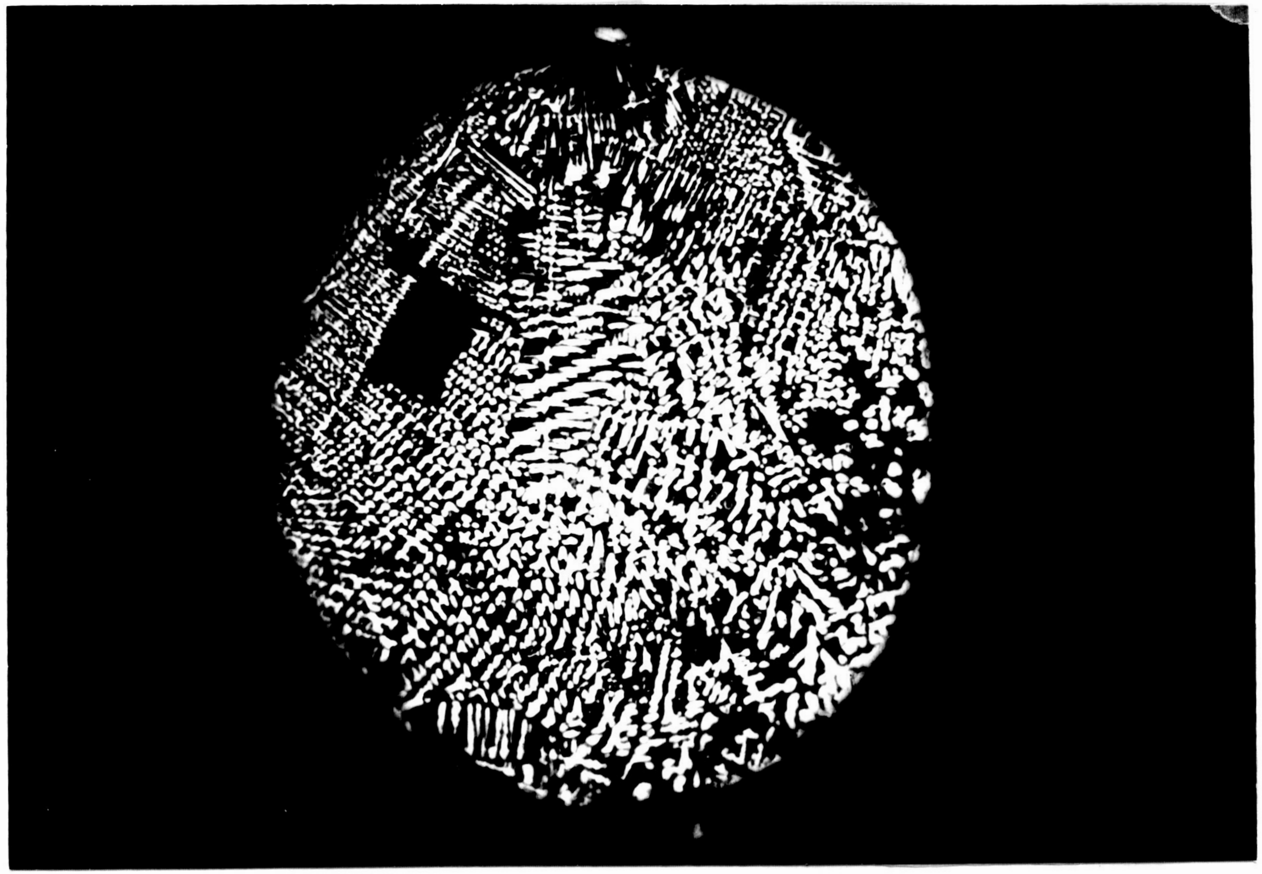

Fig. 1. Photomicrograph of a polished and etched section of a black, magnetic spherule of natural origin from Lamont core V16-30. Large diameter of spherule 250 microns. Highly reflecting network is an apparent iron oxide phase. Large black areas are regions where material was lost during polishing. Magnification 400x.

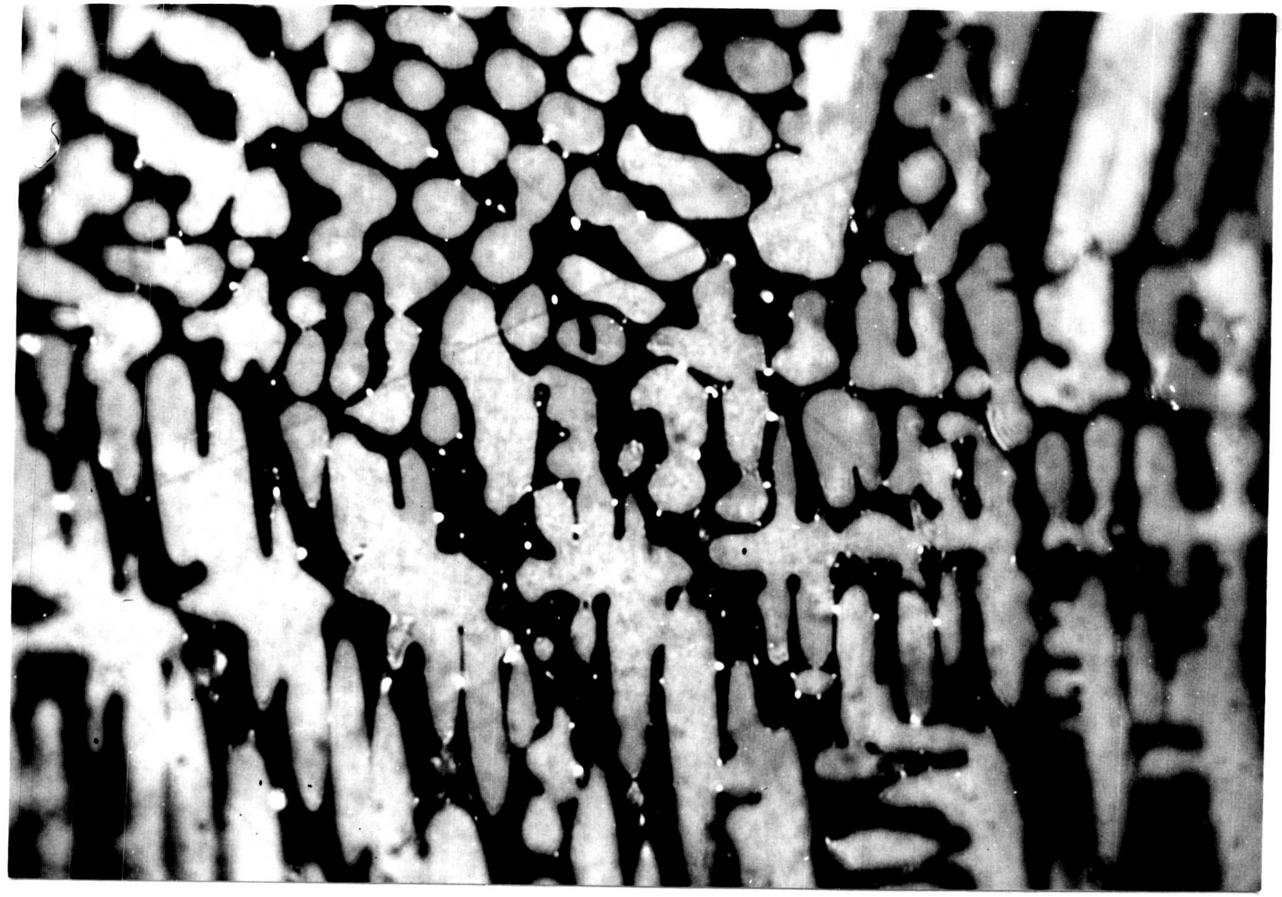

Fig. 2. Photomicrograph of central area of same spherule before etching. Specular reflections produced by metallic inclusions. Note that these tend to be located at the interfaces between the grey iron oxide phase and the matrix material. Spherule is considered to be of natural origin because it was found in ancient sediments. The presence of metallic particles is thought to preclude a volcanic origin and suggest an extraterrestrial origin. Magnification 3000x.

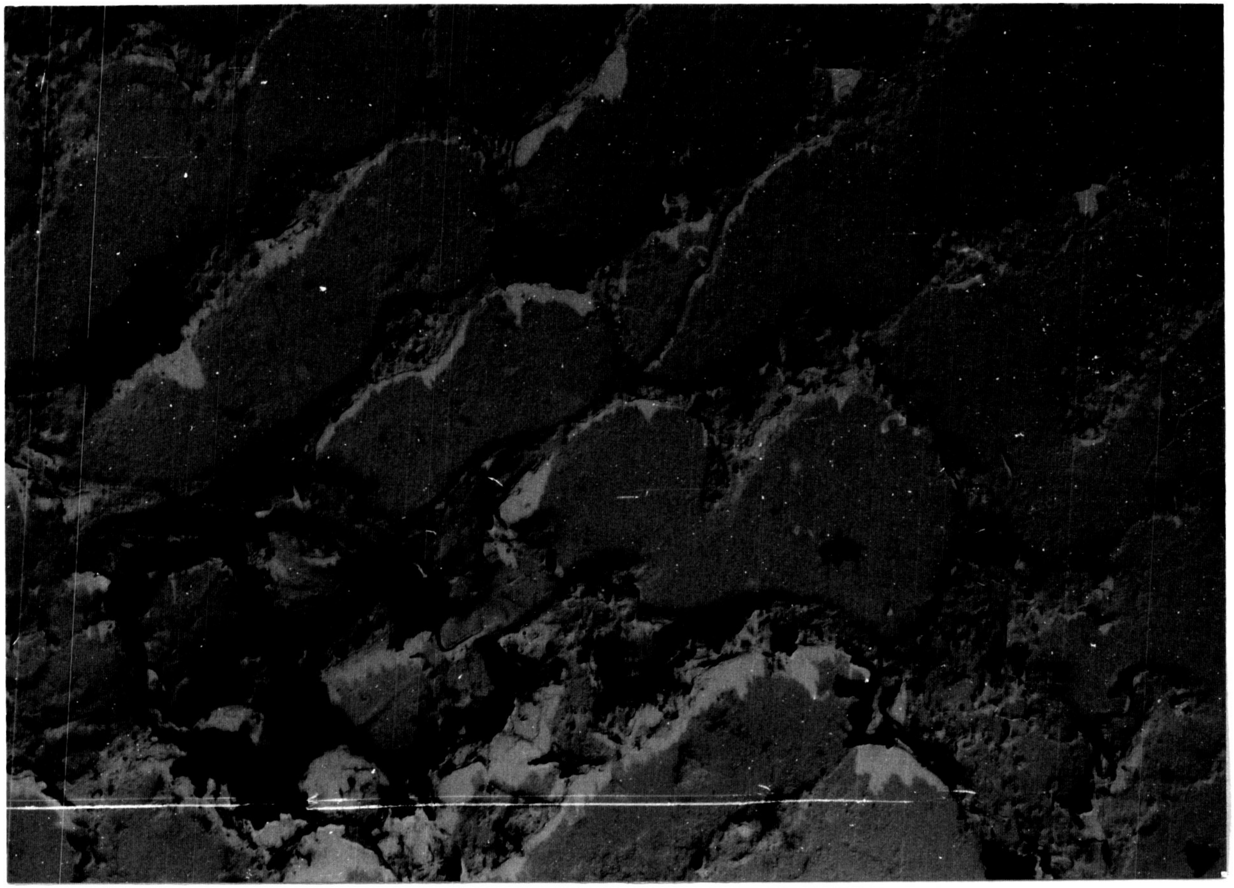

Fig. 3. Peel electron photomicrograph of strongly etched surface of spherule. Matrix material has a lumpy appearance. Black areas are matrix fragments adhering to peel. Magnification 4000x.

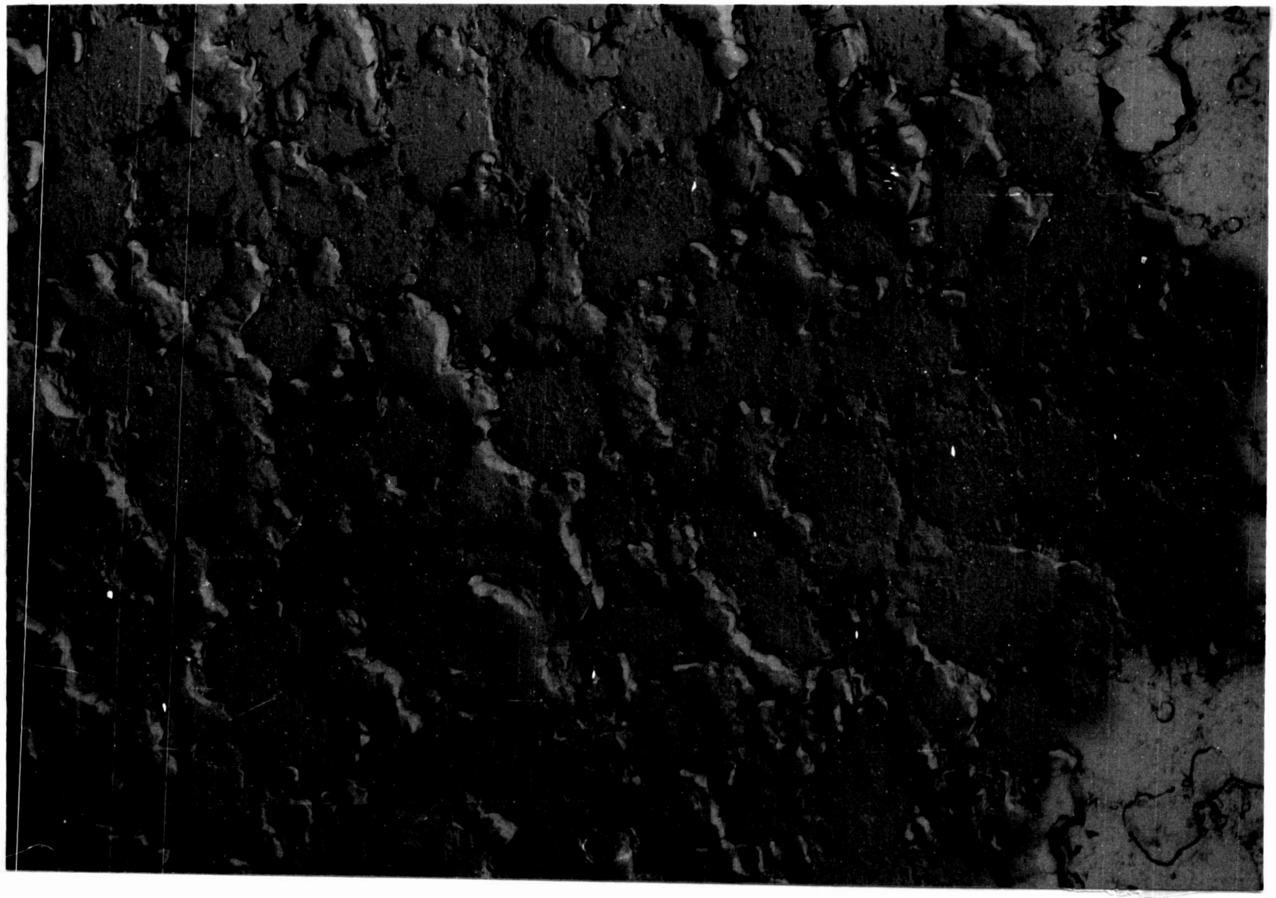

Fig. 4. A light etch of the natural spherule suggests the presence of two different grain sizes in the matrix material. Whether this is due to the etching process or not is not yet known. Magnification 4000x.

Fig. 5. Arrangement for model cratering experiments. Tripod supports a one-foot length of Primacord above the water. Blasting cap with fuse attached is inserted in upper end of Primacord. Detonation of Primacord is violent and propagates downward at 5-6 km/sec to produce shock effects.

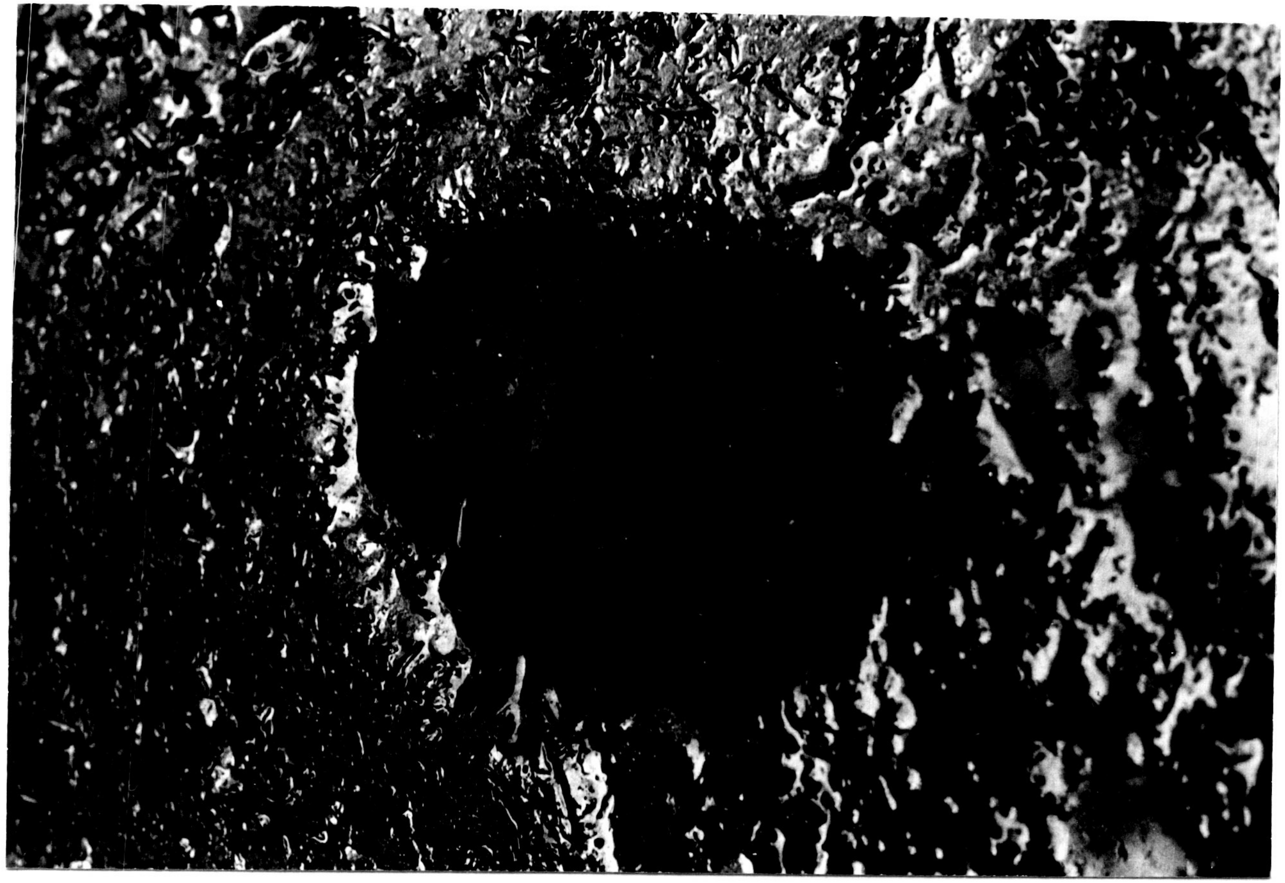

Fig. 6. Case 1. Depression in mud produced by shock effects from air blast of Primacord suspended over water. Water has been drained to show the resulting feature. Note virtual absence of rims. See Table I for dimensions.

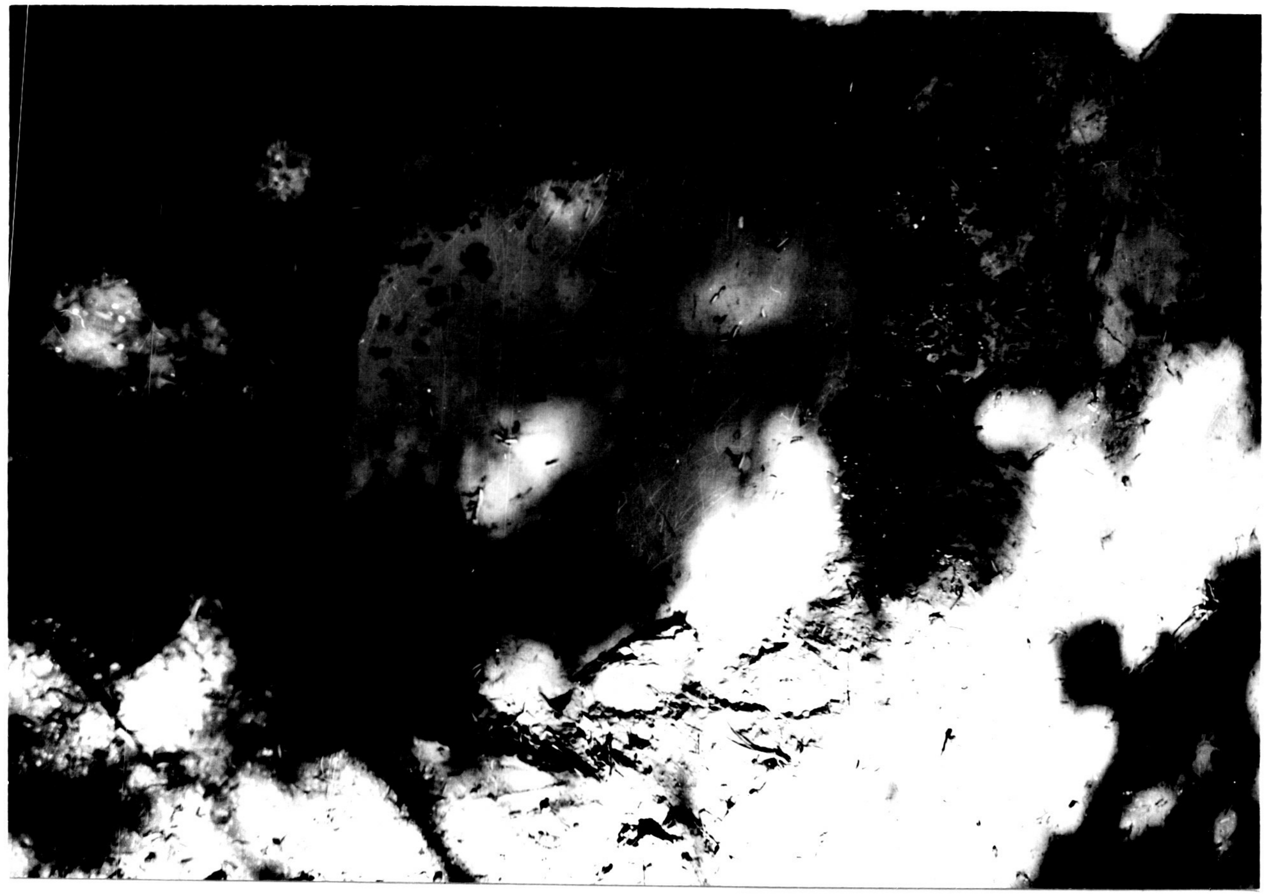

Fig. 7. Case 2. Square-shaped explosion crater produced in mud by detonation of Primacord whose end extended below water surface but did not touch mud. Note absence of raised rims. Square shape may be due to edge effects in small pond. See Table I for dimensions.

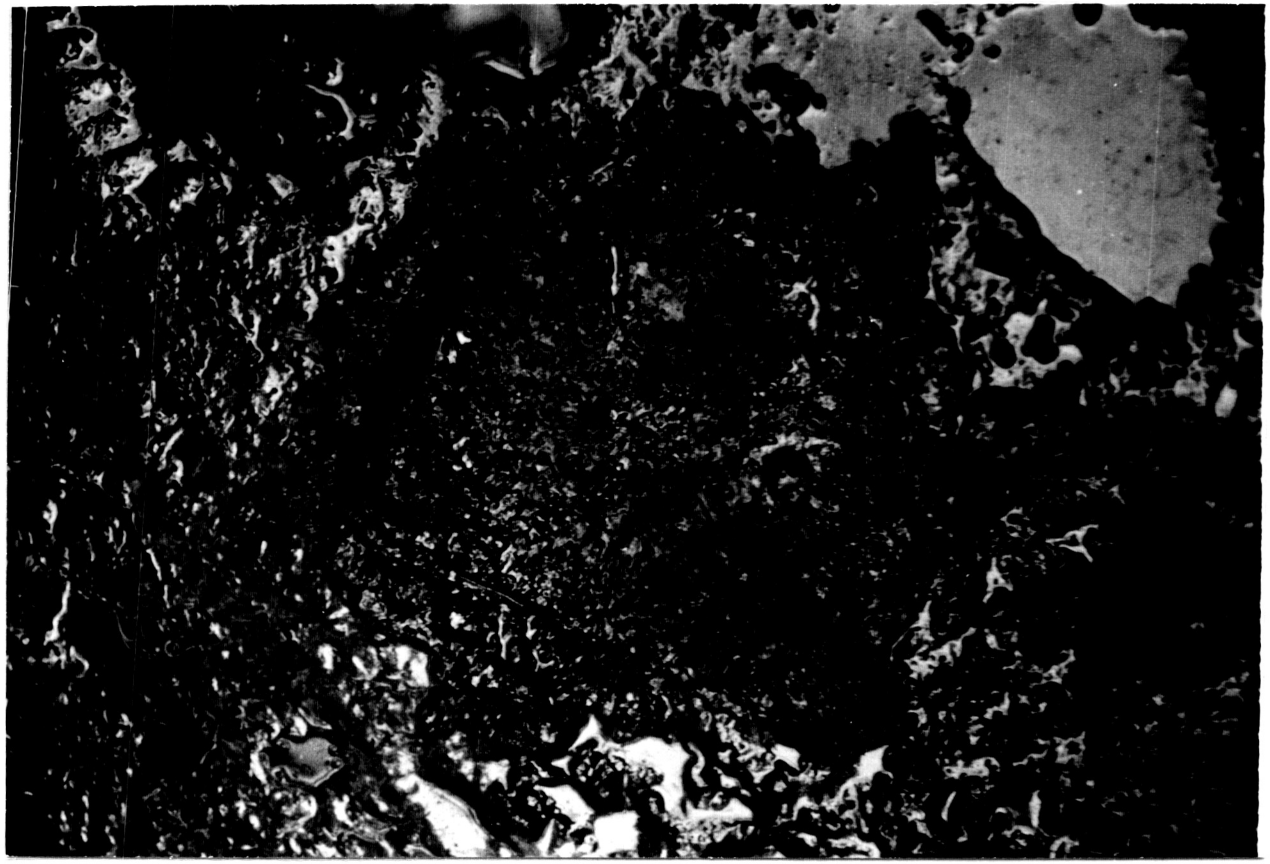

Fig. 8. Case 3. Explosion crater produced in mud by inserting the end of Primacord charge below the mud surface, with no overlying water. Note the presence of raised rims of ejecta. See Table I for dimensions.